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BI-MONTHLY STATUS REPORT

JANUARY 18TH, 2009–MARCH 18TH, 2009

SBIR PHASE I

"New In-field Composite Repair Techniques for Transmission or Distribution Pipelines"

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Bi-Monthly Report – March 18, 2009

SBIR PHASE I

1.0 PHASE I PROGRAM INTRODUCTION

In-field repair of a damaged pipeline must be performed safely, efficiently, rapidly and reliably. Reinforcement of damaged pipelines is typically accomplished by welding a repair patch and then recoating the repaired area. The welded full-encirclement sleeve is still the most common repair system due to the lower risk, potential cost savings, and simplicity of the repair. Recent developments in fiber reinforced composite repair patches have led to their increased usage across other industries. A composite repair offers an alternative to welding as the strength is claimed to be comparable. The pipeline surface conditions play a role in the long term performance of the composite patch.

Odyssian Technology will introduce a new composite repair technology that uses thermoplastic as the composite matrix in place of the conventional thermoset. A thermoset polymer sets up under heat or when mixed with a two part system having chemical hardeners. The elevated cure thermoset systems require exposure to heat over prolonged periods of time. This can be problematic during in-field repair under harsh weather conditions. A two part system can be used that significantly reduces the time of cure of the thermoset resin, yet typically at a cost to the structural performance of the polymer matrix material. Two part system achieve cross-linking or cure through the addition of hardeners. These hardeners act as catalysts to promote and accelerate cross-linking of the polymer system. The disadvantage is that they typically cause a significant reduction in mechanical properties, which can cause a corresponding reduction in compressive strength of the composite material system.

The advantage of thermoplastic over themoset is that a thermoplastic melts and fuses when heated. This process does not rely upon extended heating to cause complete cross-linking and full realization of mechanical properties. In addition, thermoplastics can be recycled which may allow the thermoplastic composite repair materials to be made from lower cost recycled plastics. Odyssian Technology will perform a design study of a composite repair wrap using layered cover that includes the use of hybrid fiber composite material with an embedded thick film of HDPE for improved toughness and sealing. A high flow bonding adhesive would be used to assure adequate fill and bonding to the aged or damaged pipe. This is a two piece configuration, with the advantage of this concept being reduced time and improved ease in repair.

The official start of this program was September 18, 2008 with completion of the scheduled technical tasks by May 1, 2009 and final reporting and documentation by May 17, 2009.

2.0 SUMMARY

During this reporting period, performance and testing standards were researched and specified. Many thermoplastic material systems were researched and the data was collected to perform a down-selection process. The results of the down-select was a 60% E-glass (or equivalent) fiber with an

HDPE resin matrix laminates bonded with high-flow adhesive. The system is designed using a Nichrome heating element for curing and is contained within a thermoformed clam-shell.

3.0 PROGRAM STATUS

The status of this program is provided in the subsequent sections. Program management status, schedule status, and financial status are discussed.

3.1 – PROGRAM MANAGEMENT STATUS

Phase I of this program is on schedule.

3.2 – SCHEDULE STATUS

The schedule was not changed during this reporting period.

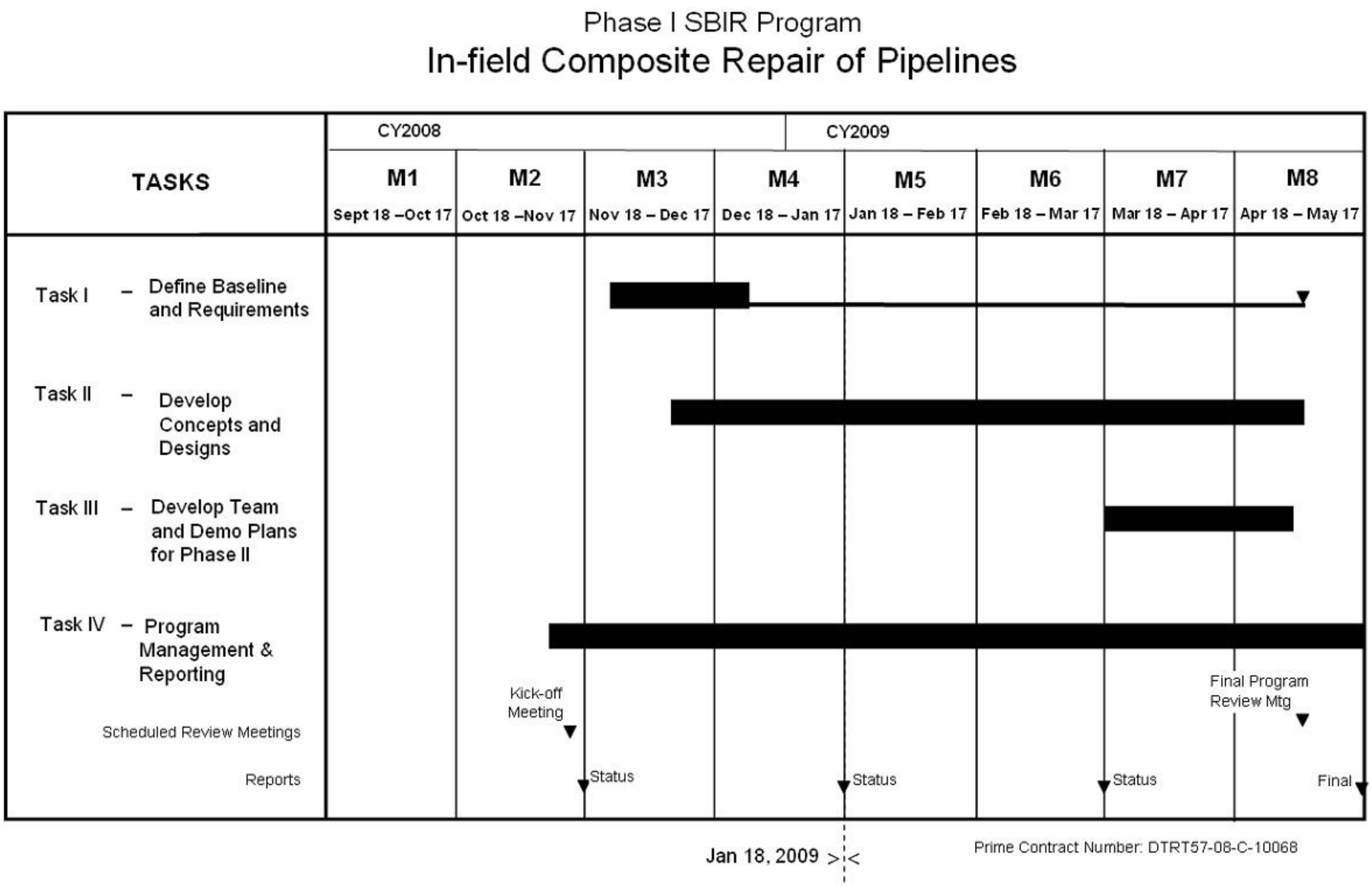

Figure 1: Revised Phase I Program Schedule

4.0 TECHNICAL STATUS & ACCOMPLISHMENTS

The work plan of this program included the following four tasks;

Task I – Define Baseline and Requirements

Task II – Develop Concepts and Designs

Task III – Develop Team and Demo Plans for Phase II

Task IV – Program Management & Reporting

4.1 – TECHNICAL ACCOMPLISHMENTS

During this reporting period, technical progress was made under Task I – Define Baseline and Requirements and Task II – Develop Concepts and Designs. A summary of this progress is provided in the following subparagraphs.

Task I – Define Baseline and Requirements

Project Definition and Rationale

During this reporting period work was done to define the scope and application of the pipe repair system. A study was done into the history and current state of the pipeline infrastructure in the United States. Figure 2 below shows the location of various hazardous liquid and natural gas pipelines in the US, a large amount is located on and around the Gulf of Mexico coastline. The statistics released by the Department of Transportation's Pipeline and Hazardous Material Safety Administration shows that out of the total mileage of pipelines as of 2003 (2,307,981 miles), only 7% constituted hazardous liquid pipelines (160,868 miles), of which pipelines carrying oil and petroleum are included, while 13% made up of interstate natural gas transmission lines (298,133 miles), and the majority 80% makes up smaller intrastate natural gas distribution lines (1,848,980 miles). A table of the mileage statistics are available in the appendix.

Current incident reports (accidents involving damaged or breached pipelines) filed by pipeline operators were compiled by the PHMSA and details the consequences to the public and pipeline industry, in terms of monetary costs and lives. The consequence statistics showed that in the time frame of 2003-2007, roughly ~$500 million in total property damage was caused by hazardous liquid pipelines with 11 fatalities and 35 injures. During this same time, natural gas gathering, distribution and transmission pipelines were responsible for ~1.2 billion dollars in total property damages with 58 fatalities and 162 injuries. The majority of cost and fatalities/injuries were the result of accidents involving natural gas distribution pipelines (~$600 million with 52 fatalities and 132 injuries). The majority of all total property damage across the four categories occurred in 2005, possibly due to Hurricane Katrina. Tables on costs and consequences of hazardous liquid and natural gas pipelines are available in the appendix.

The study showed that the majority of pipelines in the United States are natural gas distribution pipelines and that the majority of property damage cost and fatalities and injuries are resulting from accidents involving natural gas distribution pipelines. Due to the results of this study, the focus of the design is on the repair of natural gas distribution lines and to an extent natural gas transmission lines.

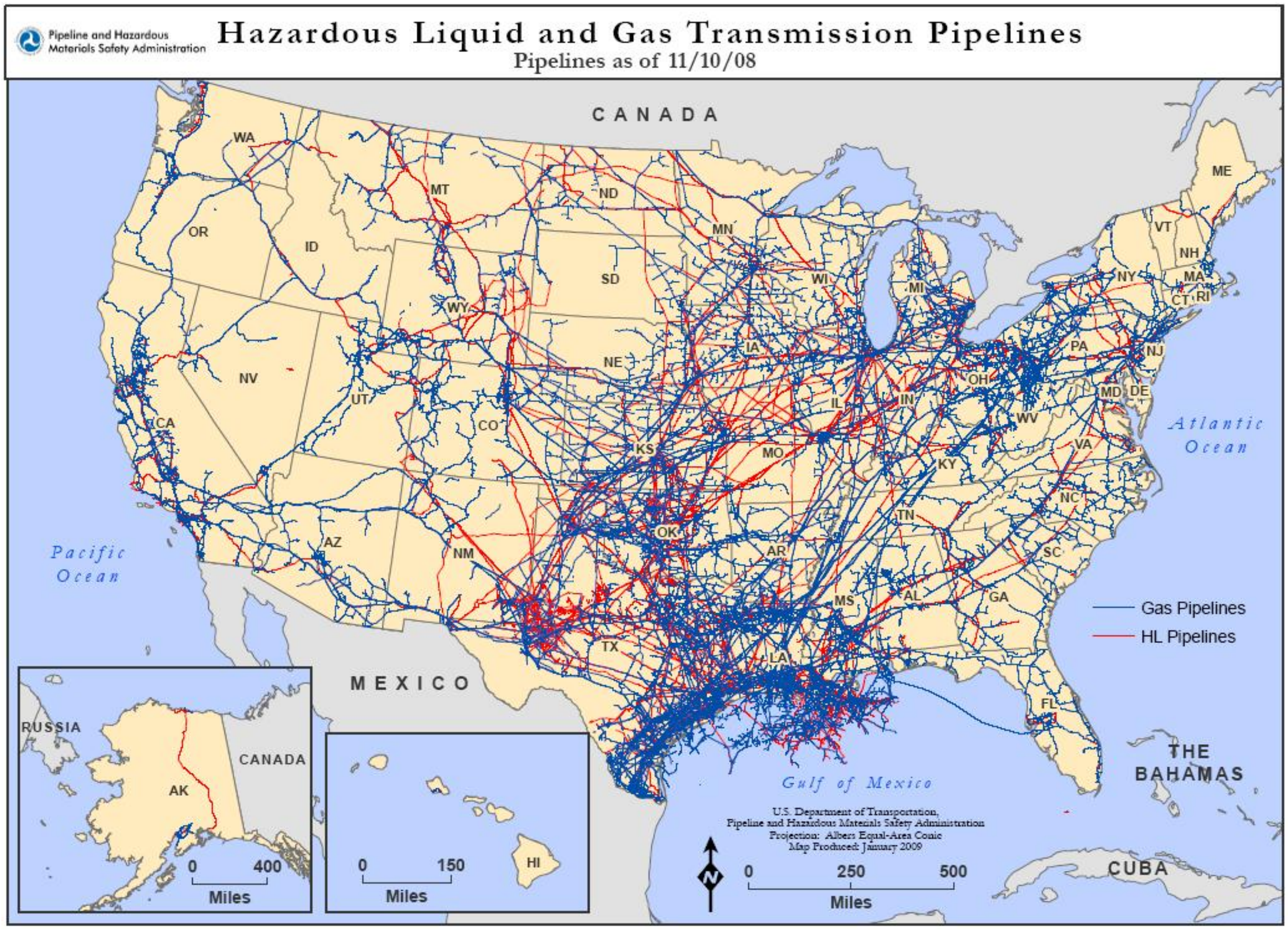

Figure 2: Hazardous liquid (i.e. petroleum) and natural gas transmission pipelines in the US

The sizing, materials, and operating pressures of natural gas transmission and distribution lines covers a wide range. Transmission pipelines for natural gas were found to have varying diameters from 6 to 36" (measured from OD) and are typically made from carbon steel material. The internal operating pressures of a NG transmission line ranges from 300 to 1500 psi. Distribution lines have smaller diameters that range from 2 to 16", and are made from steel, plastic or cast iron material. The typical operating pressures of a distribution line typically range from a quarter to 200 psi. Based on this information, a good starting point for the design of the composite repair system is decided to be a 6" steel natural gas pipe that can handle an operating pressure of up to 1500 psi.

Standards and Testing Methods

The standards pertaining to the non-metallic and bonded repairs for pipes include the federal standard released by the DOT Office of Pipeline Safety 49 CFR 192 and the ASME PCC-2. Testing standards include the ASTM standards listen below in figure 4.

Although the federal regulation standards do not list specific numbers, it does state that a composite repair system must be able to permanently restore the serviceability of the pipe. Two sections of the CFR 192 regulation address this in the repair of dents and corrosions. For repair of dents in a steel pipe, it states: "Each of the following dents must be removed from steel pipe to be operated at a pressure that produces a hoop stress of 20 percent, or more of SYMS (specified yield minimum strength), unless dent is repaired by a method that reliable engineering tests and analysis show can permanently restore the serviceability of the pipe." (49 CFR 192.309) For corrosion on a steel pipe, it states: "General corrosion. Each segment of transmission line with general corrosion and with a remaining wall thickness less than that required for the MAOP of the pipeline must be replaced or the operating pressure reduced commensurate with the strength of the pipe based on actual remaining wall thickness. However, corroded pipe may be repaired by a method that reliable engineering tests and analyses show can permanently restore the serviceability of the pipe." (49 CFR 192.485)

There are currently no minimum specified standards concerning mechanical and performance properties of composite repair system. However, for the repair and reinforcement of steel pipelines to be effective, composite materials must have adequate stiffness. A good rule of thumb is to have a material with a tensile modulus on the order of 2.5 Msi and tensile strength on the order of 50 ksi. Design considerations must also consider long-term performance as well as time and temperature-dependant material degradation issues.[1] Additional guidelines and requirements for composite repair delivered by the International Pipeline Conference are shown in the appendix, which are further extrapolated in the ASME PCC-2-2006 standards document.

When bonded composite repair systems were introduced into the oil and gas pipeline industry, Clock Spring set the standard for composite repair development. Clock Spring was recognized as the first developed composite repair system that was widely used on transmission pipelines. The repair system is made up of E-glass/polyester material and methacrylate adhesive and have typical mechanical properties shown below (figure 3). Due to the Clock Spring system being the de-facto "industry standard", its mechanical properties will be used as a guide for designing the composite repair system.

Property	***Value***
Elastic Modulus	5 Msi (0), 1.4 Msi (90)
Tensile Strength	75-100 ksi
Coefficient of thermal expansion (CTE)	6.0e-6 in/in/F (0), 3.2e-5 in/in/F (90)
Percent Strain (Elongation)	1.5 to 2%
Glass fiber content	60-70% (weight), 45-55% (volume)
Nominal thickness per ply	0.065"

Figure 3: Mechanical and physical properties of Clock Spring repair system

Testing standards for the mechanical and material properties of the composite repair system are listed in full in the figure below (figure 4). These are based upon the international ASTM standard. The most important properties to test, as listed on the ASME PCC-2 standard, are tensile, flexural,

[1] Alexander, Chris and Francini, Bob. "State of the Art Assessment of Composite Systems Used to Repair Transmission Pipelines" 6th International Pipeline Conference, 2006. IPC2006-10484

Young's modulus and Poisson's ratio, Shore hardness, CTE, and adhesive shear. Mechanical property such as tensile, flexural, compression, Young's and Poisson's, and shear can be tested using MTI-50K Universal Testing System available in the Odyssian Technology facility (see figure 5). Afterwards, the system can be sent to a testing lab for additional testing and verification.

Standard	***Description***	***Alternative***
ASTM D-695	Compression Strength and Modulus	
ASTM D-3039	Young's Modulus and Poisson's Ratio	
ASTM E-831	Coefficient of Thermal Expansion	ASTM D-696
ASTM D-790	Flexural Strength and Modulus	
ASTM D-638	Tensile Strength and Modulus	
ASTM D-1002	Composite Lap Shear Strength (Adhesion)	ASTM D-3165
ASTM D-5379	Shear Strength and Modulus	
ASTM D-6604	Composite Transition Temp of Resin	
ASTM D-2583	Shore Hardness	
ASTM G 8-96	Cathodic Disbondment	
ASTM G-14	Impact Test - Modified Gardner	
ASTM D-648	Heat Distortion Temperature	

Figure 4: List of ASTM testing standards

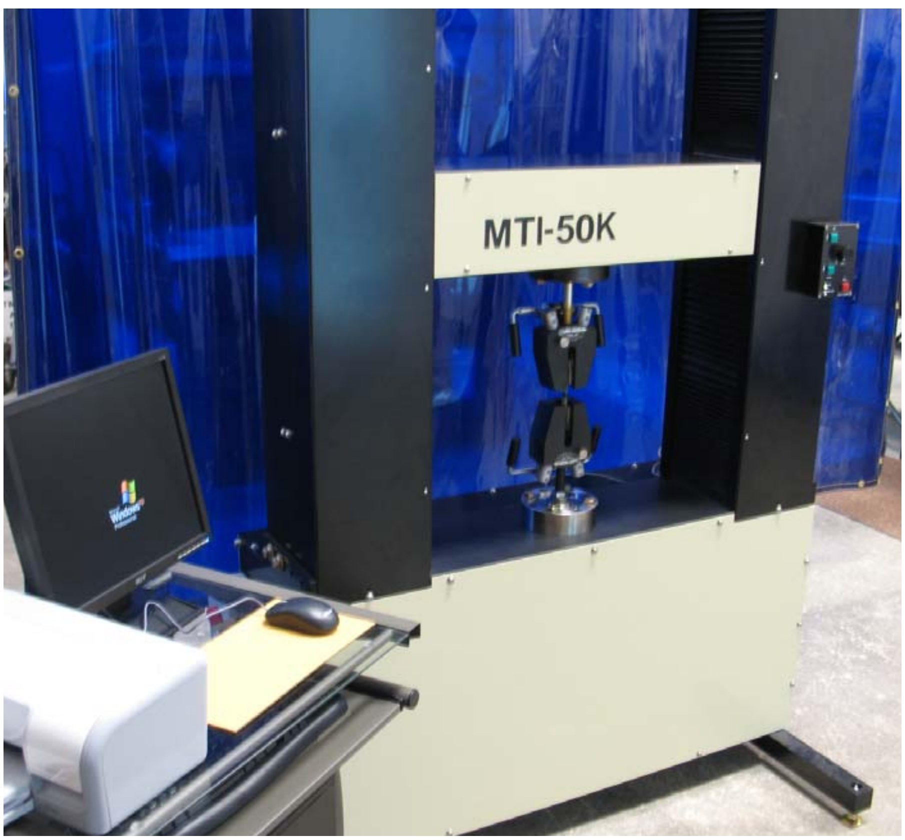

Figure 5: In-house mechanical testing system

Solicitations and Potential Partners

During this reporting period solicitations have been made with the Owens Corning Corporation. Owens Corning is the world's largest manufacturer of fiberglass and other related products as well as other building materials systems and composites. Representatives from the company expressed interest in supplying Odyssian Technology with materials needed and assist with the development of a marketable composite repair product. Owens Corning is well connected with the pipeline industry and works with various petroleum and natural gas companies in the area of pipeline maintenance and repair.

Task II – Develop Concepts and Designs

Material System Selection

During this reporting period research was done into the different thermoplastic composite material systems that could be used in designing the final repair system. A typical composite repair system consists of a fiber reinforcement, typically glass or carbon fibers that provides strength and stiffness and a resin matrix system, consisting of a thermoplastic or thermoset that is used to transfer load between fibers. An adhesive is often used to bond the composite, made up of multiple layers of fiber-resin sheets, to the pipe structure. The fiber material form can be either unidirectional or woven 0-90 bi-directional.

There were many different material systems researched during this reporting period with cost, ease of installation, and minimum performance requirements in mind. A chart of some of the material systems researched and their performance data is listed in the appendix. Once data for all the different material systems were compiled, a down selection process was used to determine the most desirable material. Consideration was given to cost and ease of processing while satisfying the design parameters mentioned in Task I.

The first and easiest selection was any material system that uses thermoplastics. To reiterate from past reports and the original proposal, the advantage of thermoplastics over themosets is that a thermoplastic melts and fuses when heated. This process does not rely upon extended heating to cause complete cross-linking and full realization of mechanical properties. In addition, thermoplastics can be recycled which may allow the thermoplastic composite repair materials to be made from lower cost recycled plastics. Other advantages include the fact that thermoset materials expire after a certain amount of time whereas thermoplastics have no shelf life. And while thermosets have higher overall material performance, it requires a more complicated curing process, such as chemical reaction (i.e. two-part epoxy, or heat induced single-part epoxy) or irradiation (i.e. electron beam processing) which increases the time to process, and cost of processing equipment. Compare this to thermoplastics, which only requires a relatively short application of heat.

The second selection was the HDPE resin. There were a variety of thermoplastics to choose from, with a range of different performance values and processing parameters. The table below (figure 6) shows the various thermoplastic resins and their mechanical performance properties, which shows a strong correlation between process temperature and performance. The higher the process temperature the higher the tensile strength and modulus. And while higher strength and modulus is ultimately desirable, the higher processing temperature means more powerful heating apparatus and a longer heat exposure time, which raises the equipment/fuel cost and time of labor. The HDPE resin has shown to satisfy the "rule of thumb" requirement in Task I for tensile strength and modulus while having the lowest required process temperature. Tensile strength can match the Clock Spring standard by raising the fiber count to 60% (by weight) from 45% listed in the appendix data table. HDPE has also shown to be common, and relatively inexpensive, which reduces the composite material system cost.

Thermoplastic Resin	*Process Temperature*	*Tensile Strength (ksi)*	*Tensile Modulus (Msi)*
High Density Polyethylene (HDPE)	350 F (175 C)	65	2.5
Polypropylene (PP)	400 F (205 C)	108	4.1
Polyamide (Nylon 6)	525 F (275 C)	--	--
Polyetherimide (PEI)	600 F (315 C)	--	--
Polyphenylene Sulfide (PPS)	625 F (330 C)	162	6.3
Polyetheretherketone (PEEK)	715 F (385 C)	175	6.5

Figure 6: List of various thermoplastic resins and their processing temperatures, E-glass reinforced and based off the values taken from the material systems data table in the appendix

The next selection was choosing E-glass continuous fiber reinforcement over carbon fibers. The table below (figure 7) shows the various fiber materials and their mechanical performance parameters. As the data shows, carbon fibers perform much better than E-glass under the same conditions and resin matrix. However, the cost of carbon fibers are approximately $20-30 per pound, while the cost of E-Glass is approximately $1 per pound, an order of magnitude less.

	50% Carbon Fibers	**47.5% E-Glass**	**50% Carbon Fibers**	**50% E-Glass**
Tensile Strength (psi)	109800	49300	95100	70200
Tensile Modulus (psi)	8100000	3100000	8100000	3800000
Flexural Strength (psi)	148900	74200	126200	97000
Flexural Modulus (psi)	8700000	3300000	7300000	4100000
Compression Strength (psi)	93300	61600	108000	105400
Compression Modulus (psi)	7500000	3700000	7500000	4200000
Resin Type	Polyphylene	Polyphylene	Polythermide	Polytherimide
Thickness	0.0122"	0.0098"	0.0122"	0.0094"
Cost	~$20-30/lb	~$1/lb	~$20-30/lb	~$1/lb

Figure 7: List of various fiber materials and their performance parameters and cost, values taken from the material systems data table in the appendix

The material system down-selection process resulted in the selection of a material repair system consisting of unidirectional E-Glass fibers (60%-70% by weight) with an HDPE resin matrix. The initial data suggests that this material system is the most cost-effective and easy to use, and satisfies both the "rule of thumb" and Clock Spring standards discussed in Task I. Further analysis and testing is needed to verify proper selection of the composite repair material system. ESR-Glass, a variant of E-glass, is also being considered due to its high corrosion-protection properties. The selection of the adhesive is in process and its results will determine the pipe-to-composite shear properties of the repair system.

Design Concepts

During this reporting period designs were made for the repair system and its associated tooling. The following paragraphs describe the design of various components and tooling assemblies for the composite repair system.

High pressure consolidation of the composite material yields a very low void content which maximizes optimum density. Therefore, the use of pre-consolidated thermoplastic panels is being considered. These panels, which are made up of multiple plies or layers of composite sheets, are consolidated under high pressure to minimize void content. Figure 8 shows a composite panel for the repair system that would be pre-consolidated in a flat shape, and subsequently formed to fit the outer diameter of the pipe to be repaired. Continuous fiber reinforcement (CFR) will increase the performance of the thermoplastic composite repair system. Reinforcements could be unidirectional or bi-directional but earlier research showed some concern over a woven fabric having the potential for fiber distortion that may occur during expansion and contraction process cycles.

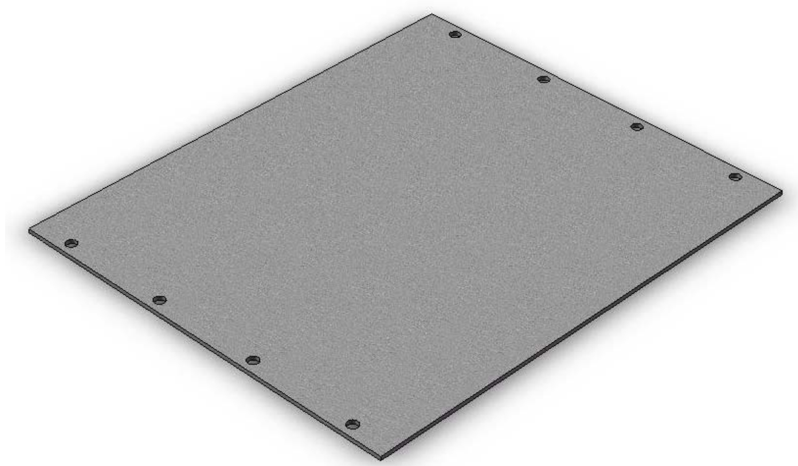

Figure 8: Pre-consolidated composite panel before forming.

Tooling designs for forming the pre-consolidated panels to the proper shape could be constructed from a variety of material. *(see Figure 9)*. The tool itself would not have to as robust because of the initial pre-processing phase. This could allow the use TIG welded aluminum form tools for a greater cost savings over billet stock.

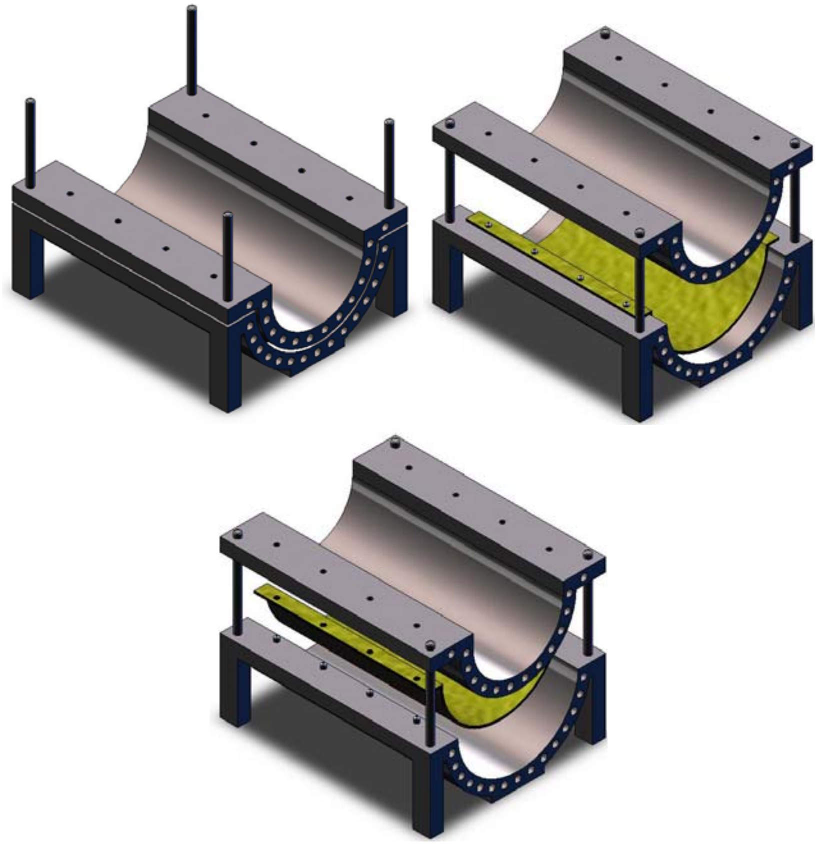

Figure 9: Tooling concept for pre-forming the HDPE pre-consolidated composite panel.

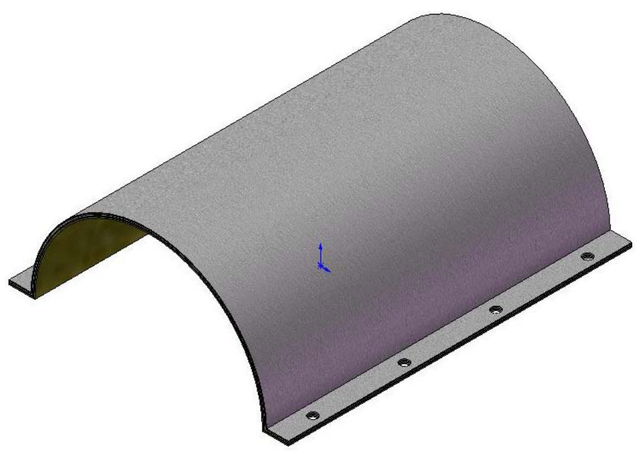

Figure 10: Thermoformed clam-shell half

The composite panels will be formed by preheating the pre-consolidated composite panels until the material becomes flexible enough to be formed. Once properly heated, the panel is formed by placing the heated panel over the correct form, clamping the tool mating halves together, and then allowing the part to gradually cool. The fundamental of heat fusion welding is to heat the HDPE surfaces to an appropriate temperature, changing the resin's molecular structure to an amorphous (pliable state), and then fuse them together by application of prescribed force (torque). During the cooling phase, the material returns to its crystalline state thus creating one homogeneous structure (see Figure 10).

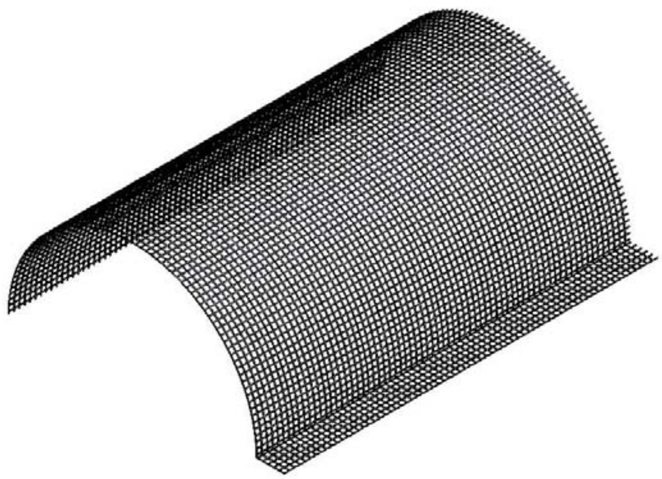

Figure 11: Nichrome heating element.

One method being investigated as a possible heat source involves nichrome wire mesh (see Figure 11). The mesh would be sandwiched in the assembly to uniformly distribute heat to the clamshell surfaces. An electrical current would cause the heating of the wires to the proper temperature after the assembly was installed on the damaged pipe section. The damaged pipe section would have all of the components assembled with a metallic over-press held together with standard fasteners with the required specified torque (see Figure 12). When fusion pressure is applied at the designated temperature and the prescribed force is applied, the thermoplastic molecules from each mating surface mix. As the joint cools, the molecules return to their crystalline form, the original interfaces have been removed, and the two halves have become one monolithic structure *(*see Figure 13*)*.

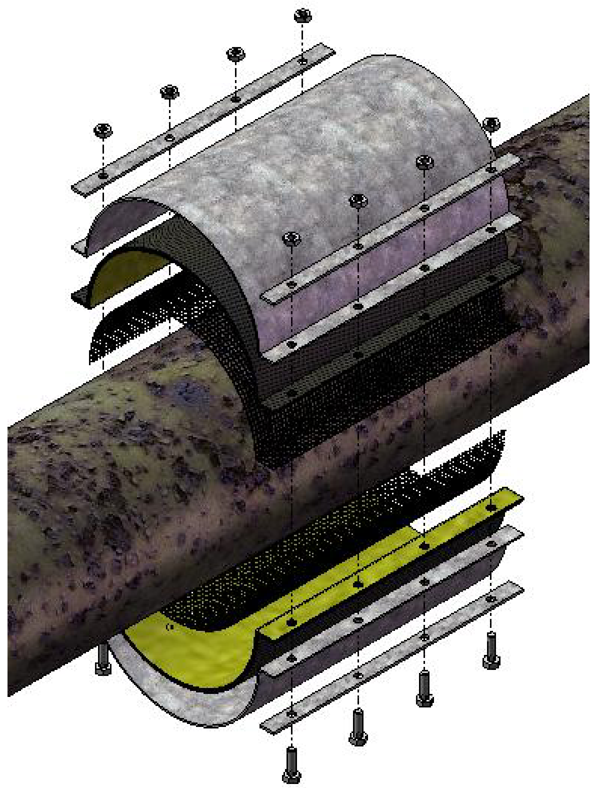

Figure 12: Exploded view of the thermoplastic composite repair system.

Figure 13: Completed thermoplastic composite repair system.

4.3 – TECHNICAL ISSUES

Currently there are no technical issues.

5.0 FUTURE PLANS

For the next reporting period work will continue on Task I – Define Baseline and Requirements and Task II – Develop Concepts and Designs. In addition, the Task III – Develop Team and Demon Plans for Phase II will be completed. Further work will also be done on the Indiana cost match grant Task I – Process Development and Evaluation and Task II – Develop Sensor Patch Design under the funding from Indiana Match.

APPENDIX

Mileage Statistics of Hazardous Liquid and National Gas Pipelines

http://www.phmsa.dot.gov/portal/site/PHMSA/menuitem.ebdc7a8a7e39f2e55cf2031050248a0c/?vgnextoid=a62924cc45ea4110VgnVCM1000009ed07898RCRD&vgnextchannel=80837e2cd44d3110VgnVCM1000009ed07898RCRD&vgnextfmt=print

Type of pipeline		**Mileage**	**Total**
Hazardous Liquid (2003)		160,868	160,868
Natural Gas Transmission			
	Gathering lines	19,864	
	Transmission lines	278,269	
Total			**298,133**
Natural Gas Distribution (2001)			
	Distribution Mains	1,119,430	
	Distribution Service Lines	729,550	
Total			**1,848,980**
	Grand Total:		**2,307,981**

Consequences Summary Statistics for Natural Gas and Hazardous Liquid Pipelines

http://primis.phmsa.dot.gov/comm/reports/safety/CPI.html?nocache=9757

National Hazardous Liquid: Consequences Summary Statistics: 2003-2007

Year	Public Fatalities		Industry Fatalities		Public Injuries		Industry Injuries		Total Property Damage [B] [C]	Damage to Public Property [D] [B]		Damage to Industry Property [E] [B]		Value of Product Lost [B]	
2003	0	0%	0	0%	0	0%	5	100%	$54,538,762	$31,011,307	56%	$22,034,644	40%	$1,492,811	2%
2004	5	100%	0	0%	15	93%	1	6%	$159,374,542	$33,755,694	21%	$122,841,426	77%	$2,777,421	1%
2005	0	0%	2	100%	2	100%	0	0%	$165,063,016	$84,036,748	50%	$77,548,196	47%	$3,478,072	2%
2006	0	0%	0	0%	2	100%	0	0%	$62,150,187	$19,855,728	31%	$38,032,187	61%	$4,262,271	6%
2007	2	50%	2	50%	9	90%	1	10%	$50,594,673	$18,982,971	37%	$28,072,501	55%	$3,539,201	7%
Totals	7	63%	4	36%	28	80%	7	20%	$491,721,182	$187,642,449	38%	$288,528,955	58%	$15,549,777	3%

National Gas Transmission: Consequences Summary Statistics: 2003-2007

Year	Public Fatalities		Industry Fatalities		Public Injuries		Industry Injuries		Total Property Damage [B] [C]	Damage to Public Property [D] [B]		Damage to Industry Property [E] [B]		Value of Product Lost [B]	
2003	0	0%	1	100%	3	37%	5	62%	$56,232,363	$11,407,440	20%	$27,054,585	48%	$17,770,337	31%
2004	0	0%	0	0%	0	0%	2	100%	$38,262,823	$174,417	0%	$28,571,481	74%	$9,516,923	24%
2005	0	0%	0	0%	2	40%	3	60%	$237,212,368	$92,511,087	39%	$120,315,593	50%	$24,385,687	10%
2006	1	33%	2	66%	1	25%	3	75%	$38,827,402	$2,706,730	7%	$28,860,670	74%	$7,260,002	18%
2007	1	50%	1	50%	1	14%	6	85%	$53,907,130	$793,500	1%	$35,294,884	65%	$17,818,746	33%
Totals	2	33%	4	66%	7	26%	19	73%	$424,442,088	$107,593,176	25%	$240,097,214	56%	$76,751,697	18%

National Gas Gathering: Consequences Summary Statistics: 2003-2007

Year	Public Fatalities		Industry Fatalities		Public Injuries		Industry Injuries		Total Property Damage [B] [C]	Damage to Public Property [D] [B]		Damage to Industry Property [E] [B]		Value of Product Lost [B]	
2003	0	0%	0	0%	0	0%	0	0%	$2,004,378	$1,571,384	78%	$152,888	7%	$280,104	14%
2004	0	0%	0	0%	0	0%	1	100%	$35,512,213	$10,935	0%	$34,249,286	96%	$1,251,992	3%
2005	0	0%	0	0%	0	0%	2	100%	$154,202,256	$113,403	0%	$152,378,741	98%	$1,710,111	1%
2006	0	0%	0	0%	0	0%	1	100%	$11,304,786	$0	0%	$10,606,866	93%	$697,920	6%
2007	0	0%	0	0%	0	0%	0	0%	$5,512,694	$0	0%	$5,087,126	92%	$425,568	7%
Totals	0	***%	0	***%	0	0%	4	100%	$208,536,329	$1,695,723	0%	$202,474,909	97%	$4,365,696	2%

National Gas Distribution: Consequences Summary Statistics: 2003-2007

Year	Public Fatalities		Industry Fatalities		Public Injuries		Industry Injuries		Total Property Damage [B] [C]	Damage to Public Property [D] [B]		Damage to Industry Property [E] [B]		Value of Product Lost [B]	
2004	13	100%	0	0%	22	66%	11	33%	$32,407,600	$24,222,505	74%	$6,983,318	21%	$1,201,776	3%
2005	11	78%	3	21%	31	79%	8	20%	$536,955,458	$27,200,095	5%	$504,283,125	93%	$5,472,238	1%
2006	10	62%	6	37%	11	42%	13	50%	$19,862,069	$17,656,433	88%	$1,891,623	9%	$314,012	1%
2007	7	77%	2	22%	23	63%	13	36%	$23,434,503	$20,043,622	85%	$3,114,135	13%	$276,746	1%
Totals	41	78%	11	21%	87	64%	45	33%	$612,659,631	$89,122,656	14%	$516,272,202	84%	$7,264,773	1%

Design Guidelines: Minimum Requirements for Composite Pipe Repair

The following list compiled reflects the minimum requirements that any composite repair should meet.

1. The composite material used in the repair system should possess sufficient tensile strength. The combination of the remaining pipe wall and composite material should possess a long term failure strength that is at least equal to the specified minimum yield strength (SMYS) of the pipe material. Although a strength equal to 100 percent SMYS is sufficient, one option is to recommend that a safety factor be placed on the maximum operating pressure (MOP) and determine the required number of wraps based on this pressure. If MOP is assumed to be 72 percent, a safety factor of two corresponds to a stress level of 144 percent SMYS. While this may be an overly-conservative safety factor, the unknowns relating to the long-term performance of composites in aggressive soil environments require that a conservative position be taken.

2. The material should demonstrate that it can perform adequately in repairing corroded pipelines. This involves strength in burst mode, but also involves ensuring that the repair does not degrade with time or cyclic pressure service. Experimental testing must be conducted to address this issue. In addressing the effects of cyclic operating pressures, the service conditions in actual operating lines should be considered. A typical liquid pipeline may experience approximately 1,800 cycles per year (at a 200 psi pressure differential), while gas transmission lines see 10 times fewer, or 60 cycles, for the same pressure level.

3. Testing should be conducted to address long term behavior of the material under dead weight loading. Idealistically, a battery of tests should be conducted using weights as a percentage of the lower bound failure load for the given material. The testing should be conducted so that failures occur over loading time periods up to 1,000 hours at a minimum (longer if possible).

4. Lap shear testing should be conducted to ensure that an adequate bond exists between the pipe and wrap. For composite repair methods that are not monolithic (monolithic meaning that all layers combine to form a homogenous unit), these tests should also include composite-composite test samples as well as the composite-steel test coupons. The composite-composite sample is used to assess the bond strength between the layers, while the composite-steel samples are used to determine the lap shear strength at the interface between the pipe material and composite.

5. Testing should be conducted to address cathodic disbondment and the system should meet the requirements as set forth in ASTM G8 (Standard Test Methods of Cathodic Disbonding for Pipeline Coatings).

6. Repair materials should resist mild acid and alkaline environments, including a range of 4 to 11 pH. Alkaline soils may have a pH of 11 or higher, which will attack fiberglass and polyester resin. In general, epoxies can handle mild acids and strong alkalines.

7. Testing should be conducted to address water penetration into the system using test method ASTM G9 (Standard Test Method for Water Penetration and Pipeline Coatings).

8. The composite material should be able to withstand temperatures of the operating line on which it is to be installed. The operator should consider the effects of temperature in selecting regions of application (e.g. compressor station may see temperatures of 200F).

9. Product must be environmentally-safe and possess low toxicity for the applicator.

10. To minimize the possibility for improper installation, the system must be user-friendly and have instructions that are easily understood. For two-part systems, the greatest problem associated with improper application involves incorrect mixing of the adhesive. Installation should only be conducted by a certified applicator.

11. The product must have clearly stated on it the expiration date (if applicable) of any component within the system. The system must demonstrate that it possesses adequate strength over a long period of time (2 to 3 year testing period). This should involve testing of the composite itself as well as adhesive bonds under load. Samples should be exposed to harsh environments (such as saturation in water) where composite properties are known to degrade with time.

12. A field monitoring program should be conducted to assess performance of the wrap over several years. This involves inspection of the buried line at least one year after installation. The repair should be inspected for soundness and any possible signs of degradation. If possible, strain gages should be installed beneath the wrap to determine any changes in the pipe strain that occur with time.

13. The adhesive system must demonstrate that it can be used in a variety of temperature environments and permit installation in a range of ambient temperature conditions (e.g. between 0F and 120F). Ultimate responsibility is on the operator to ensure that the system can adequately cure and is not damaged at elevated ambient conditions.

14. For cold weather applications, the system should have sufficient toughness to ensure that the material does not become brittle and lose its ability to properly reinforce the pipeline.

15. When a repair method is used for restoring corroded pipes, calculations relating to its strength should incorporate severity of the corrosion using methods such as those used in ANSI/ASME B31G. This is especially important considering that most of the wet lay-up system permit the number of wraps to be varied depending on the severity of corrosion level.

Material Systems Data

The following material system data was taken from TenCate Advanced Composites USA, Inc. The results are taken at room temperature (72 F) at 50% humidity. The reason for taking all the data from one manufacturer was for consistency when comparing different material systems side-by-side.

Material Systems Properties (CFR)

	CETEX PPS	**CETEX PPS**	**CETEX PEI**	**CETEX PEI**
Tensile Strength (psi)	109800	49300	95100	70200
Tensile Modulus (psi)	8100000	3100000	8100000	3800000
Flexural Strength (psi)	148900	74200	126200	97000
Flexural Modulus (psi)	8700000	3300000	7300000	4100000
Percent Elongation	3	3	7	7
Compression Strength (psi)	93300	61600	108000	105400
Compression Modulus (psi)	7500000	3700000	7500000	4200000
Poisson's Ratio - Hoop	0.36	0.36	0.36	0.36
Coefficient of Thermal Expansion	52.2 um/m-C	52.2 um/m-C	55.8 um/m-C	55.8 um/m-C
Glass Transition Temperature	194 F	194 F	419 F	419 F
Process Temperature	212 F	212 F	392 F	392 F
Fiber Type	*Carbon Fabric (50%)*	*E-Glass (47.5%)*	*Carbon (50%)*	*E-Glass (50%)*
Resin Type	Polyphylene	Polyphylene	Polytherimide	Polytherimide
Architecture	Unidirectional	Unidirectional	Unidirectional	Unidirectional
Thickness	0.0122"	0.0098"	0.0122”	0.0094"
Resin Material System	Thermoplastic	Thermoplastic	Thermoplastic	Thermoplastic

	Thermo-Lite 4245E	**Thermo-Lite 4060R**	**Thermo-Lite 4268I**	**Thermo-Lite 4268P**
Tensile Strength (psi)	65000	108000	175000	162000
Tensile Modulus (psi)	2500000	4100000	6500000	6300000
Flexural Strength (psi)		85000	185000	174000
Flexural Modulus (psi)		3800000	6400000	6200000
Compression Strength (psi)			170000	161000
Compression Modulus (psi)			6400000	6000000
Poisson's Ratio - Hoop				
Coefficient of Thermal Expansion				
Glass Transition Temperature				
Process Temperature	350 F	400 F	725 F	625 F
Fiber Type	E-Glass (45%)	E-Glass (60%)	E-Glass (68%)	E-Glass (68%)
Resin Type	*Polyethylene*	*Polypropylene*	*PEEK*	*PPS*
Architecture	Unidirectional	Unidirectional	0-90 bidirectional	0-45-90 Directional
Thickness	0.02"	0.01"	0.0093"	0.0076"
Resin Material System	Thermoplastic	Thermoplastic	Thermoplastic	Thermoplastic